

APPENDIX I - Glossary of Terms

The following are definitions of terms as they are utilized in this document.

Action integral. The action integral is a critical factor in the extent of damage. It relates to the energy deposited or absorbed in a system. However, the actual energy deposited cannot be defined without a knowledge of the resistance of the system. For example, the instantaneous power dissipated in a resistor is i^2R , and is expressed in watts. For the total energy expended, the power must be integrated over time to get the total watt-seconds (or joules). By specifying the integral $i^2(t)$ over the time interval involved, a useful quantity called the action integral is defined for application to any resistance value of interest.

Actual transient level. The actual transient level is the level of transient voltage and/or current which appears at the equipment interfaces as a result of the external environment. This level may be less than or equal to the transient control level but should not be greater.

Aircraft lightning interaction. An encounter with lightning that produces sufficient skin/structure current and/or voltages to pose a threat to the aircraft electrical/electronic systems, as a result of a direct lightning attachment.

Aperture. An electromagnetically transparent opening.

Aperture coupling. The process of inducing voltages or currents in avionic wiring or systems by electric or magnetic fields passing through apertures.

Attachment point. A point of contact of the lightning flash with the aircraft.

Beam leads. Fine conductors that make electrical connections within semiconductor devices.

Charge transfer. The charge transfer is defined as the integral of the current over its entire duration, $i(t)dt$, in coulombs.

Component damage. Component damage is that condition where the electrical characteristics of a circuit component are permanently altered so that it no longer performs to its specifications.

Continued safe flight and landing. This phrase means that the aircraft is capable of safely aborting or continuing a takeoff; continuing controlled flight and landing, possibly using emergency procedures but without requiring exceptional pilot skill or strength. Some aircraft damage may occur as a result of the failure condition or upon landing. For airplanes, the safe landing must be accomplished at a suitable airport. For rotorcraft, this means maintaining the ability of the rotorcraft to cope with adverse operating conditions and to land safely at a suitable site.

Critical. Functions whose failure would contribute to or cause a failure condition which would prevent the continued safe flight and landing of the aircraft.

Current redistribution. The process by which electric current distribution through the entire structure changes over the duration of a lightning current pulse.

Diffusion. The process by which electric current flow spreads through the thickness of a conductive material which results in a slower increase in current density on interior surfaces as compared with exterior surfaces.

Direct effects. Any physical damage to the aircraft and/or electrical/electronic systems due to the direct attachment of the lightning channel. This includes tearing, bending, burning, vaporization or blasting of aircraft surfaces/structures and damage to electrical/electronic systems.

Equipment interface. A location on an equipment boundary where connection is made to the other components of the system of which it is part. It may be an individual wire connection to an electrical/electronic item, or wire bundles that interconnect equipment. It is at the equipment interface that the equipment transient design level (ETDL) and transient control level (TCL) are defined and where the actual transient level (ATL) should be identified.

Equipment transient design level (ETDL). The equipment transient design level is the peak amplitude of transients to which the equipment is qualified.

Equipment transient susceptibility level. The transient peak amplitude which will result in damage or upset to the system components.

Essential. Functions whose failure would contribute to or cause a failure condition which would significantly impact the safety of the aircraft or the ability of the flightcrew to cope with adverse operating conditions.

External environment. Characterization of the natural lightning environment for design and certification purposes as defined in Appendix III.

Immunity. The capacity of a system or a piece of equipment to continue to perform its intended function in an acceptable manner, in the presence of electrical transients due to an aircraft lightning interaction.

Induced voltages. A voltage produced in a circuit by changing magnetic or electric fields or structural IR voltages.

Indirect effects. Electrical transients induced by lightning in aircraft electric circuits.

Internal environment. The fields and structural IR potentials (produced by the external environment), along with the voltages and currents induced by them.

Lightning channel hang-on. A lightning attachment which should be considered to persist at a single point for the duration of the lightning flash.

Lightning flash. The total lightning event. It may occur within a cloud, between clouds, or between a cloud and ground. It can consist of one or more strokes, plus intermediate or continuing currents.

Lightning leader. The leader is the preliminary breakdown that forms an ionized path for charge to be channeled towards the opposite charge center. The "stepped" leader advances in a series of short, luminous steps prior to the first return stroke. The "dart" leader reionizes the return stroke path in one luminous step prior to each subsequent return stroke in the lightning flash.

Lightning strike. Any attachment of the lightning flash to the aircraft.

Lightning strike zones. Aircraft surface areas and structures classified according to the possibility of lightning attachment, dwell time and current conduction. See Appendix III.

Lightning stroke (return stroke). A lightning current surge that occurs when the lightning leader makes contact with the ground or another charge center.

Line replaceable unit (LRU). The element of a system which may be removed and replaced by a line maintenance crew while the aircraft is in operational status.

Margin. The difference between the equipment transient design level and the transient control level.

Multiple burst. A randomly spaced series of bursts of short duration, low amplitude current pulses, with each pulse characterized by rapidly changing currents (i.e. high di/dt 's). These bursts may result from lightning leader progression or branching, and are associated with the cloud-to-cloud and intracloud flashes. The multiple bursts appear to be most intense at the time of initial leader attachment to the aircraft (see Appendix III).

Multiple strike. Two or more lightning strikes during a single flight.

Multiple stroke. Two or more lightning return strokes occurring during a single lightning flash (see Appendix III).

Peak rate of rise. The peak rate of rise of a waveform is the maximum instantaneous slope (rate of change) of the waveform as it rises to its maximum value. Mathematically, the peak rate of rise of a function of time $i(t)$ is the maximum value of the derivative with respect to time of $i(t)$ and may be expressed as follows:

$$\text{Peak rate of Rise} = \text{Maximum of } \frac{d[i(t)]}{dt}$$

Restrike. A subsequent stroke in a lightning flash.

Return stroke. (see Lightning Stroke)

Structural IR voltage. The structural IR voltage is the portion of the induced voltage resulting from the product of the distributed lightning current (I) and the resistance (R) of the aircraft skin or structure.

Swept stroke. A series of successive attachments due to sweeping of the flash across the surface of the aircraft by the motion of the aircraft.

System functional upset. An impairment of system operation, either permanent or momentary (e.g., a change of digital or analog state) which may or may not require manual reset.

Transient control level (TCL). The transient control level is the maximum allowable level of transients appearing at the equipment interfaces as a result of the defined external environment.

Upset. (See System functional upset)

APPENDIX II - Location of Lightning Strike Zones

The locations of each zone on a particular aircraft may be determined as follows:

(a) Extremities such as the nose, wing and empennage tips, tail cone, wing mounted nacelles and other significant projections should be considered as within a direct strike zone because they are possible initial leader attachment points. Those that are forward extremities or leading edges should be considered in Zone 1A, and extremities that are trailing edges should be in Zone 1B. Some of the time, the first return stroke will arrive shortly after the leader has attached to the aircraft, so Zone 1A is limited to the immediate vicinity (i.e., 18 in. [0.5m] or so) aft of the forward extremity. In other cases the return stroke may arrive somewhat later, thereby exposing surfaces further aft to this environment. This should be considered if the possibility of a flight safety hazard due to a Zone 1A strike to an unprotected surface is high. Where questions arise regarding the identification of initial attachment locations or where the airframe geometry is unlike conventional designs for which previous experience is available, scale model attachment point tests may be in order.

(b) Surfaces directly aft of Zone 1A should be considered as within Zone 2A. Generally, Zone 2A (swept stroke zone) will extend the full length of the surface aft of Zone 1A, such as the fuselage, nacelles and portions of the wing surfaces.

(c) Trailing edges of surfaces aft of Zone 2A should be considered Zone 2B, or Zone 1B if initial attachment to them can occur. If the trailing edge of a surface is totally nonconductive, then Zone 2B (or 1B) should be projected forward to the nearest conductive surface.

(d) Surfaces approximately 18 in. (0.5m) to either side of initial or swept attachment points established by steps (a) and (b) should also be considered as within the same zone, to account for small lateral movements of the sweeping channel and local scatter among attachment points. For example, the tip of a wing would normally be within Zone 1A (except for its trailing edge, which would usually be in Zone 1B). To account for lateral motion of the channel and scatter, the top and bottom surfaces of the wing 18 in. (0.5m) inboard of the tip should also be considered as within the same zones.

(e) Surfaces of the vehicle for which there is a low possibility of direct contact with the lightning channel should be considered in Zone 3. Surfaces and structures which lie within or between other zones are also within Zone 3. Zone 3 areas may conduct all of the lightning currents that enter/exit from Zones 1A or 1B.

Note: Due to the unique construction and operation of rotorcraft (i.e., the vehicle may be airborne with little or zero airspeed) the swept stroke phenomenon may not be applicable, and therefore attachment points at leading edges, frontal surfaces or any lower extremities may receive all components of the flash and be within Zone 1B.

APPENDIX III - External Environment - Synthesized Waveforms

1. Idealized Component Waveforms. The waveforms defined below are idealized representations of a severe natural lightning environment for certification purposes in the assessment of the induced effects of lightning. The waveforms of components A, B, C, and D are derived from cloud-to-ground lightning discharges. Component H represents the high rate of rise effects including those from intracloud and cloud-to-cloud discharges.

These waveforms can be used as the basis for either tests or analyses of the effects of a severe lightning environment on aircraft electrical/electronic systems. Due to physical constraints, test waveforms may only be approximations of the idealized waveforms. Results from test waveforms that deviate from the idealized waveforms must therefore be analytically relatable to the idealized waveform.

Note: To address the direct effects on structures and electrical/electronic systems or components, use of the waveforms and criteria contained in Paragraph 11 of AC 20-53 is recommended. For indirect effects evaluation, not all waveforms contained in AC 20-53 are applicable and the waveforms and procedures contained in this appendix should be utilized.

a. Lightning Strike Environment. There are five current component waveforms (A, B, C, D and H) that are applied in accordance with the lightning strike zone(s) that the system is located within.

(1) Component A - First Return Stroke Current - Component A has a peak amplitude of 200 kA, an action integral ($\int i^2(t)dt$) of $2 \times 10^6 A^2s$ and a double exponential waveform. This waveform represents a first return stroke of 200,000 amperes and a rate-of-rise of $1 \times 10^{11} A/s$ at $t=0.5 \mu s$. It has a peak rate of rise of $1.4 \times 10^{11} A/s$ at $t=0+$. This waveform is defined mathematically by the following equation:

$$i(t) = I_o (e^{-at} - e^{-bt})$$

Where

$$I_o = 218,810 \text{ (A)}$$

$$a = 11,354 \text{ (s}^{-1}\text{)}$$

$$b = 647,265 \text{ (s}^{-1}\text{)}$$

$$t = \text{time (s)}$$

The waveform is shown in Figure AIII-1.

(2) Component B - Intermediate Current - Component B has an average amplitude of 2 kA and a charge transfer of 10 coulombs. For analysis, a double exponential current waveform should be used. This waveform is described mathematically by the following equation:

$$i(t) = I_o (e^{-at} - e^{-bt})$$

Where

$$I_o = 11,300 \text{ (A)}$$

$$a = 700 \text{ (s}^{-1}\text{)}$$

$$b = 2000 \text{ (s}^{-1}\text{)}$$

$$t = \text{time (s)}$$

This waveform is shown in Figure AIII-1.

(3) Component C - Continuing Current - Component C is a rectangular waveform delivering 200 coulombs of charge at a rate of between 200A and 800A in a time period of between 1s and 0.25s respectively. For analysis purposes, a rectangular waveform of 400A for a period of 0.5 second should be utilized. This component transfers a charge of 200 coulombs. The primary purpose of this waveform is charge transfer. This waveform is shown in Figure AIII-2.

(4) Component D - Restrike Current - Component D has a peak amplitude of 100 kA and an action integral of $0.25 \times 10^6 \text{A}^2\text{s}$. This waveform represents a restrike of 100,000 amperes peak and a rate-of-rise of $1 \times 10^{11} \text{A/s}$ at $t=0.25 \mu\text{s}$ and a peak rate of rise of $1.4 \times 10^{11} \text{A/s}$ at $t=0+$. The waveform is defined mathematically by the double exponential expression shown in the following equation:

$$i(t) = I_o (e^{-at} - e^{-bt})$$

Where:

$$\begin{aligned} I_o &= 109,405 \text{ (A)} \\ a &= 22,708 \text{ (s}^{-1}\text{)} \\ b &= 1,294,530 \text{ (s}^{-1}\text{)} \\ t &= \text{time (s)} \end{aligned}$$

The current waveform is shown in Figure AIII-2.

(5) Component H - Multiple Burst Component - Component H has a peak current of 10 kA and a peak rate of rise of $2 \times 10^{11} \text{A/s}$ at $t=0+$. The waveform is defined mathematically by the double exponential expression shown in the following equation:

$$i(t) = I_o (e^{-at} - e^{-bt})$$

Where:

$$\begin{aligned} I_o &= 10,572 \text{ (A)} \\ a &= 187,191 \text{ (s}^{-1}\text{)} \\ b &= 19,105,100 \text{ (s}^{-1}\text{)} \\ t &= \text{time (s)} \end{aligned}$$

The current waveform is shown in Figure AIII-3.

2.0 Application.

2.1 Purposes of the Waveforms and Components.

Current Components A, B, C, D, and H together comprise the important characteristics of a severe natural lightning flash current although not all of the components may attach everywhere on the aircraft. Components A, B, D and H are described by double exponential expressions to provide the important waveshape characteristics such as rise and decay times, rate of rise, peak amplitude and charge transfer or action integral. Component C is a rectangular current pulse that transfers most of the charge in a lightning flash. Components B and C are described herein for completeness only. Indirect effects resulting from these waveforms are insignificant. The current components applicable to specific areas are described in Section 2.2 of this appendix, which relates the current components to the lightning strike zones. Guidance for locating strike zones on a particular aircraft is presented in Appendix II.

A typical cloud-to-ground lightning flash contains more than one restrike, a severe version of which is represented by Component D. In fact, flashes containing up to 24 strokes, randomly spaced, have been recorded. For protection against direct effects it is adequate to consider only one return stroke or restrike (Component A or D) because this is assumed to occur anywhere within the appropriate strike Zone (1B, 2A or 2B). However, for evaluation of indirect effects it is necessary to consider the multiple-stroke nature of an actual lightning flash, because the succession of strokes may induce corresponding pulses in data transfer circuits (for example) causing upset or cumulative damage to sensitive systems or devices. For this purpose, the following multiple stroke flash has been defined, using as a basis the definitions of Components A (first return stroke) and D (restrike).

The synthesized multiple stroke waveform is defined as an A current component followed by 23 restrikes of peak amplitude of 50,000 amperes each, as shown in Figure AIII-4. The 23 restrikes are distributed over a period of up to 2 seconds according to the following constraints:

- The minimum time between subsequent strokes is 10 ms.
- The maximum time between subsequent strokes is 200 ms.

The restrikes have waveform parameters identical to the D current component with the exception that $I_0=54,703$ amperes. Because most of an airframe is located within Zone 3 as well as one or more of the other zones, the multiple stroke environment is nearly always applicable. However, there may be special cases in Zone 2 where the aircraft system or subsystem and its wiring is isolated from the effects of the initial A current component and is therefore not exposed to the A component current or fields. In these special cases, the multiple stroke still applies but the first current component can be reduced from a peak of 200,000 amperes to 100,000 amperes. The applicant should coordinate this reduction in multiple stroke environment with the FAA on a case by case basis.

Component H represents a high rate of rise pulse whose amplitude and time duration are much less than those of a return stroke. Such pulses have been found to occur randomly throughout a lightning flash, interspersed with the other current components. While not likely to cause physical damage to the aircraft or electronic components, the random and repetitive nature of these pulses may cause interference or upset to certain systems. The recommended waveform comprises repetitive Component H waveforms in 24 sets of 20 pulses each, distributed over a period of up to two seconds, as shown in the multiple burst waveform in Figure AIII-5. The minimum time between individual Component H pulses within a burst is 10 μ s, the maximum is 50 μ s. The 24 bursts are distributed over a period of up to two seconds according to the following constraints:

- The minimum time between subsequent bursts is 10 ms.
- The maximum time between subsequent bursts is 200 ms.

Note: The multiple stroke and multiple burst environments are not intended to be applied to the full vehicle in a test. The multiple stroke and burst internal environment may be determined by testing using a single component to obtain the transfer function of interest, or to obtain the actual transient

response level. The independent responses should then be repeated and spaced as described in Figures AIII-4 and AIII-5 and used repeatedly for upset assessment. An analysis of the system or equipment to be assessed should be carried out to determine pulse spacing(s) associated with systems or equipment susceptibility for the multiple stroke and burst waveforms. The resultant values should be used to space the independent responses in a sequence of 24 bursts. It should be shown by analysis or test that, by virtue of system design, architecture, hardware or software measures, there is sufficient immunity or recovery of the system from this environment. Acceptable methods are described in the User's Manual to this document.

A summary of the parameters of the idealized lightning current waveforms is given in Table AIII-1.

2.2 Zone Application of Current Components. Current Components A, B, C, D, and H and the multiple-stroke and multiple burst waveforms may be utilized for analyses or test purposes, or for combinations thereof. The appropriate current component(s) for each zone of the aircraft are shown in Table AIII-2. When the area of interest includes more than one zone, the protection assessment shall be performed utilizing the zone or zones with the most severe environment.

Zoning is used to determine the current path(s) through the aircraft and in locating the particular path(s) which represent(s) the most severe threat to the system under investigation. For most applications, the airframe is located in Zone 3 as well as one or more of the other zones (i.e. Zone 1A, 2A, or 2B). The applicable current components from Table AIII-1 are then applied together with the multiple stroke and multiple burst environments to determine the resulting internal environment.

TABLE AIII-1 - SUMMARY OF IDEALIZED WAVEFORM PARAMETERS

<u>Parameter</u>	<u>Severe stroke (Component A)</u>	<u>Intermediate Current (Component B)</u>	<u>Continuing Current (Component C)</u>	<u>Restrike (Component D)</u>	<u>Multiple Stroke (1/2 Component D)</u>	<u>Multiple Burst (Component H)</u>
I_o (A)	218,810	11,300	400	109,405	54,703	10,572
a (s^{-1})	11,354	700	Not Applicable	22,708	22,708	187,191
b (s^{-1})	647,265	2,000	Not Applicable	1,294,530	1,294,530	19,105,100

These equations produce the following characteristics:

i_{peak}	200 KA	4,173 A	400 A	100 KA	50 KA	10 KA
$(di/dt)_{max}$ (A/s) @ $t = 0+sec$	1.4×10^{11}	Not Applicable	Not Applicable	1.4×10^{11}	0.7×10^{11}	2×10^{11}
di/dt (A/s) @ $t = 0.5 \mu s$	1.0×10^{11}	Not Applicable	Not Applicable	1.0×10^{11} @ $t = 0.25 \mu s$	0.5×10^{11} @ $t = 0.25 \mu s$	Not Applicable
Action Integral (A^2s)	2.0×10^6	Not Applicable	Not Applicable	0.25×10^6	0.062×10^6	Not Applicable

Table AIII-2 - Zonal Application of the External Environment for Determination of Indirect Effects

Zone	Current Waveforms					
	A	B	C	D	Multiple Stroke	Multiple Burst
1A	X	X			X	X
1B	X	X	X	X	X	X
2A		X		X	X	X
2B		X	X	X	X	X
3	X	X	X	X	X	X

Note: Indirect effects resulting from Components B and C are usually insignificant.

2.3 Test Waveforms. The idealized severe waveforms in Paragraph 1 of this appendix are appropriate for analysis, but they are often difficult to apply to full scale vehicles in a test program. This is because the cost to develop and operate simulators which can deliver the severe environments may become prohibitive, especially to large vehicles such as transport aircraft. Therefore, the approach for testing full scale vehicles will frequently involve the use of waveforms other than the idealized waveforms of Section 1. However, these alternate waveforms must have the property that test results can be readily extrapolated or scaled to those which would be obtained if the vehicle were tested with the idealized waveforms. Three examples of test waveforms which can achieve the desired results are as follows:

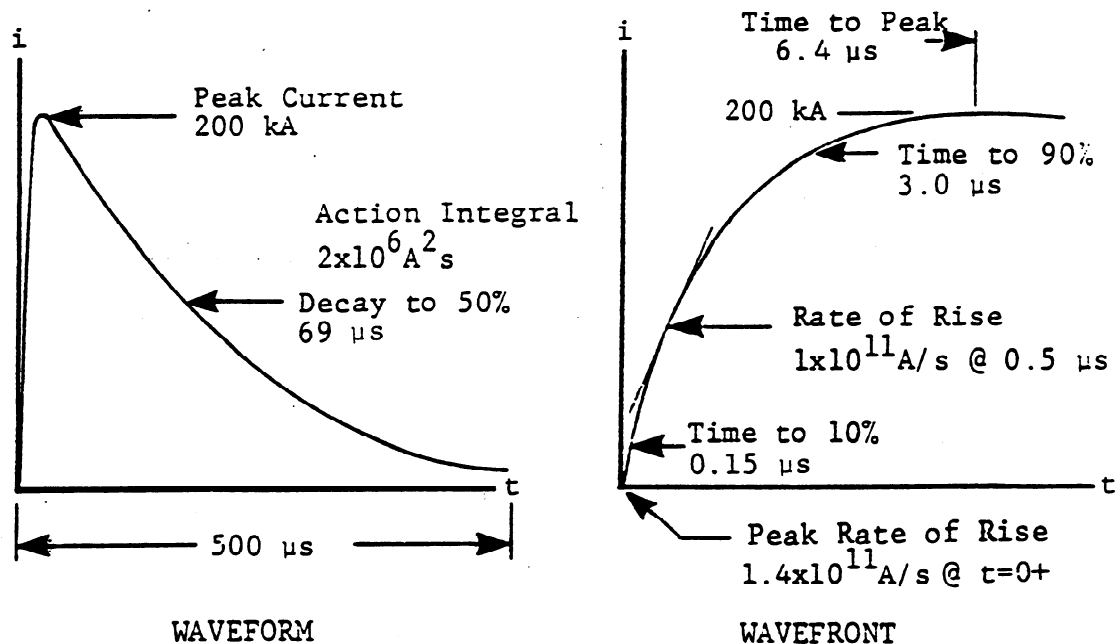
a. The first and simplest approach is the use of current waveforms which have the same waveshape as the idealized waveforms but with a much smaller amplitude. This has the great advantage that test results (measured cable currents and voltages) obtained in this way can be scaled to threat levels by a simple scalar multiplication. This approach assumes linearity, which usually is a valid assumption, and is often conservative. The larger this scale factor becomes, however, the more uncertain is the reading. Therefore, a general guideline is to test at levels as high as possible consistent with safety and other considerations.

b. A second low level approach is the swept continuous wave (CW) method. In this approach a network analyzer system is used to obtain the frequency dependent transfer function (amplitude and phase) between the lightning current waveform and aircraft cable responses. Fourier analysis techniques are then used to obtain the temporal response to the idealized waveform. This approach also assumes linearity, and has the advantage that instrumentation and computers can be used to automate the entire package, so that the process becomes less labor intensive.

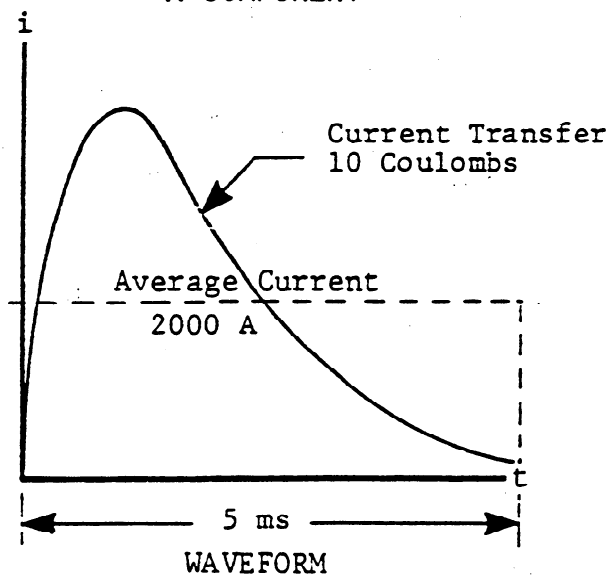
c. The third approach involves the use of a damped sinusoid generator with a rather large value of i and di/dt . This is useful because it is much less expensive to build such a generator for high levels than it is to build a high level double exponential generator. The important parameters of the peak current and its temporal derivative can then be achieved.

Such waveforms are shown as G1 and G2 of Figure AIII-6. The lower frequency sinusoid is useful for studying both aperture coupling and diffusion and current redistribution effects. The higher frequency sinusoid is useful for aperture coupling.

Test results obtained in this third approach also need to be extrapolated to the idealized waveform parameters. This becomes more difficult because it must be known if the measured coupling depends principally on the peak current amplitude or the current derivative.

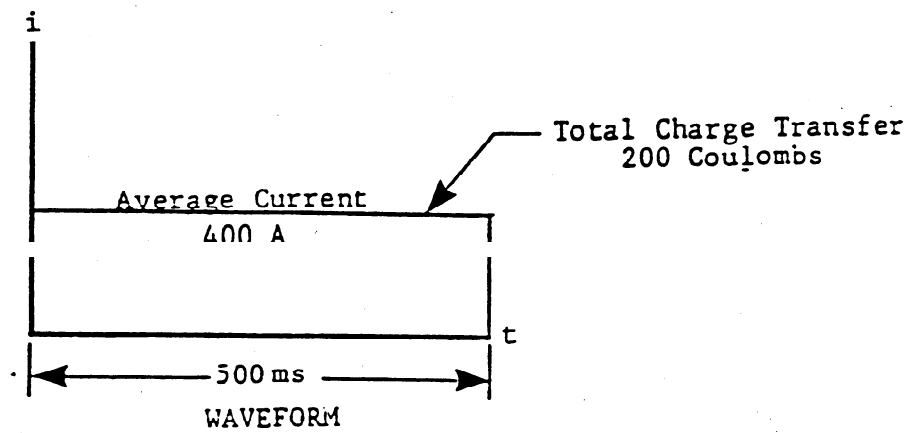


A COMPONENT

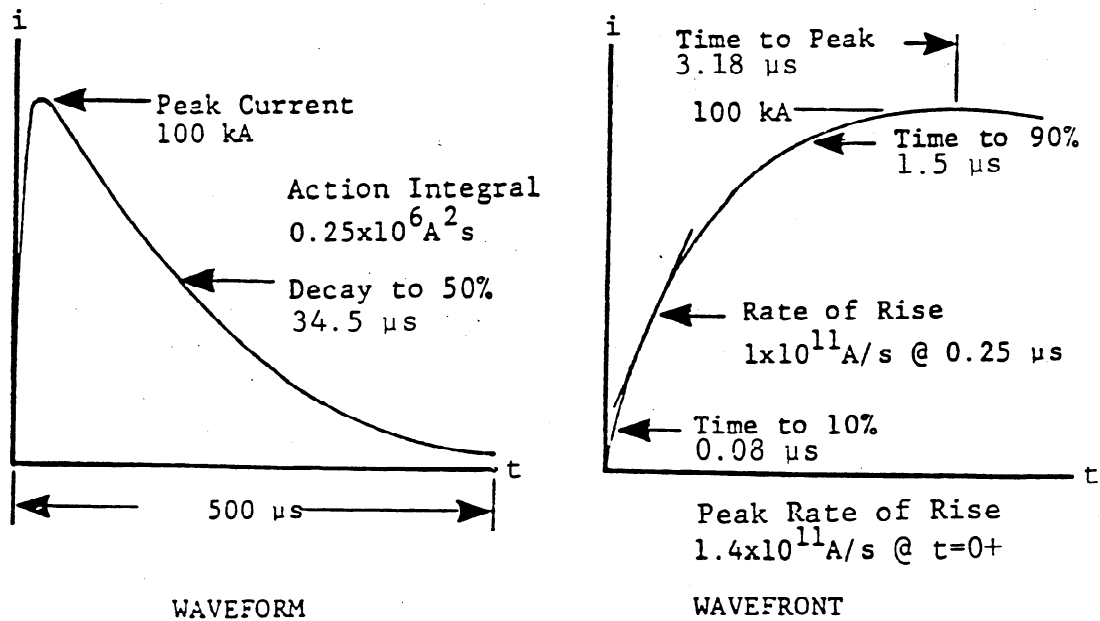


B COMPONENT

Figure AIII-1. Waveforms of Current Components A and B



C COMPONENT



D COMPONENT

Figure AIII-2. Waveforms of Current Components C and D

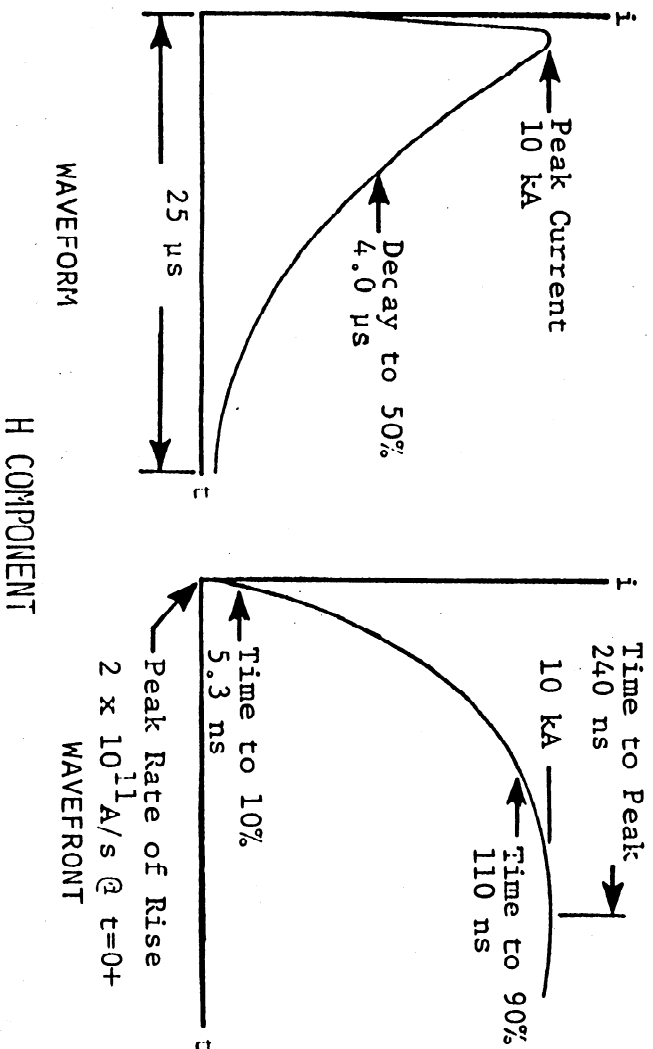
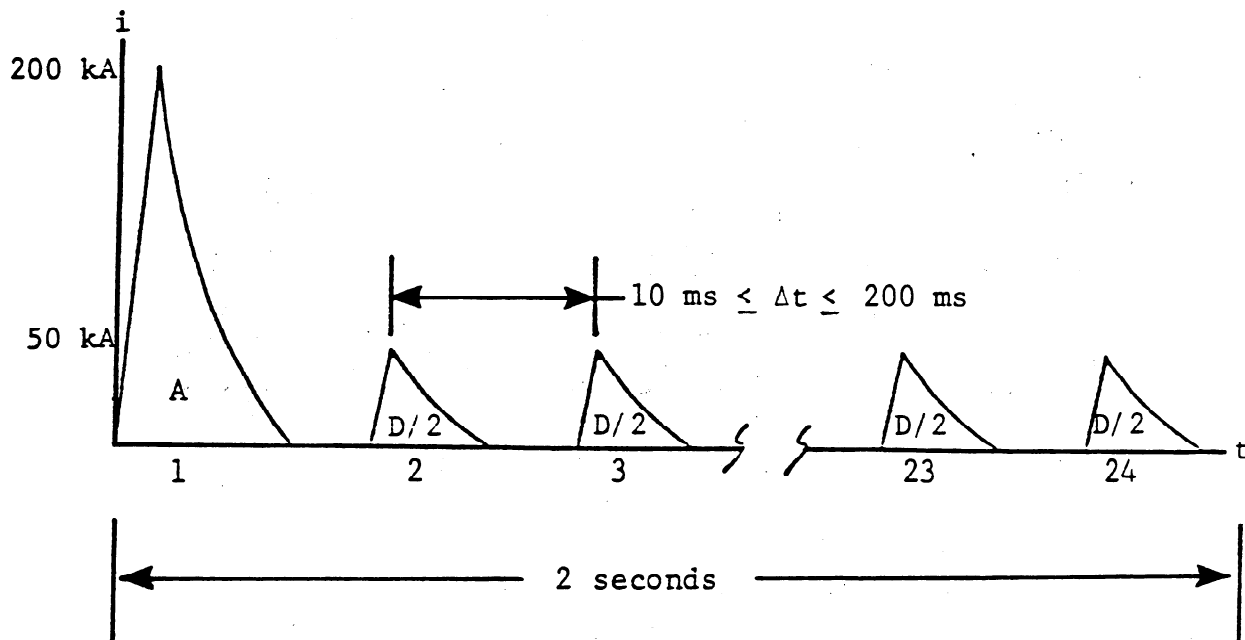
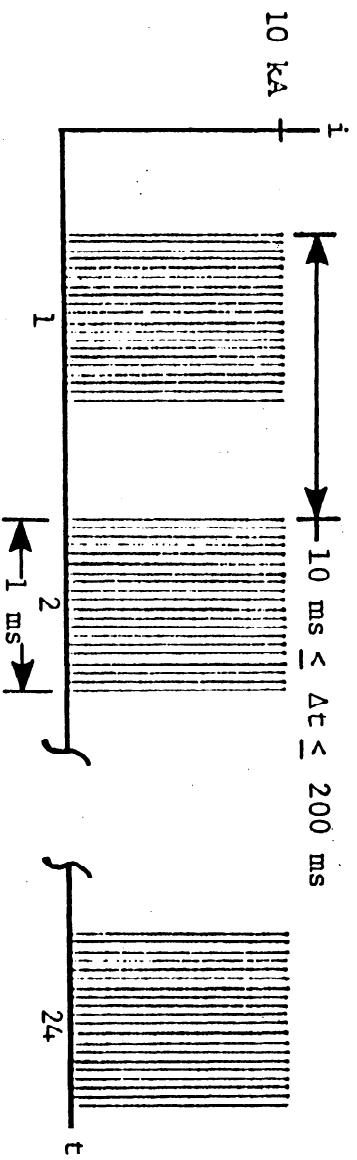
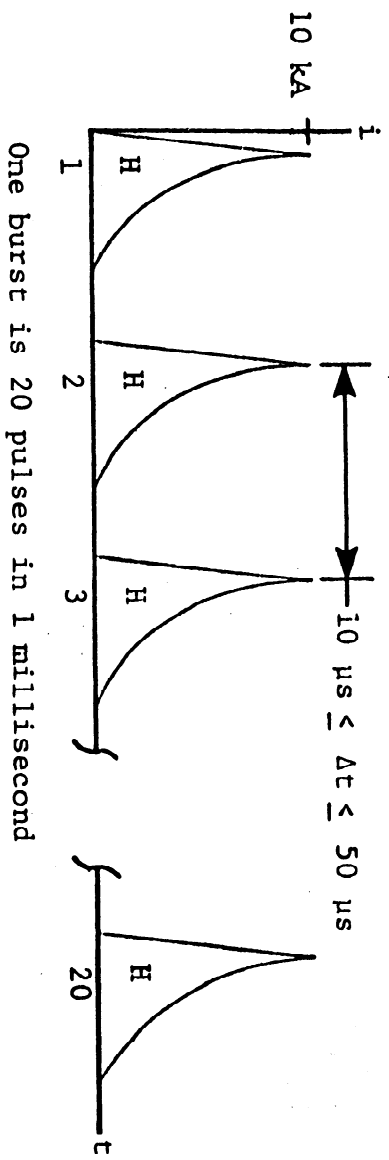


Figure AIII-3. Waveform of Current Component H



One current component A followed by twenty-three current component D's at half amplitude, as described in section 2.1, distributed over a period of up to two seconds.

Figure AIII-4. Multiple Stroke Flash



Twenty-four bursts distributed over a period of up to 2 seconds

Figure AIII-5. Multiple Burst Waveform

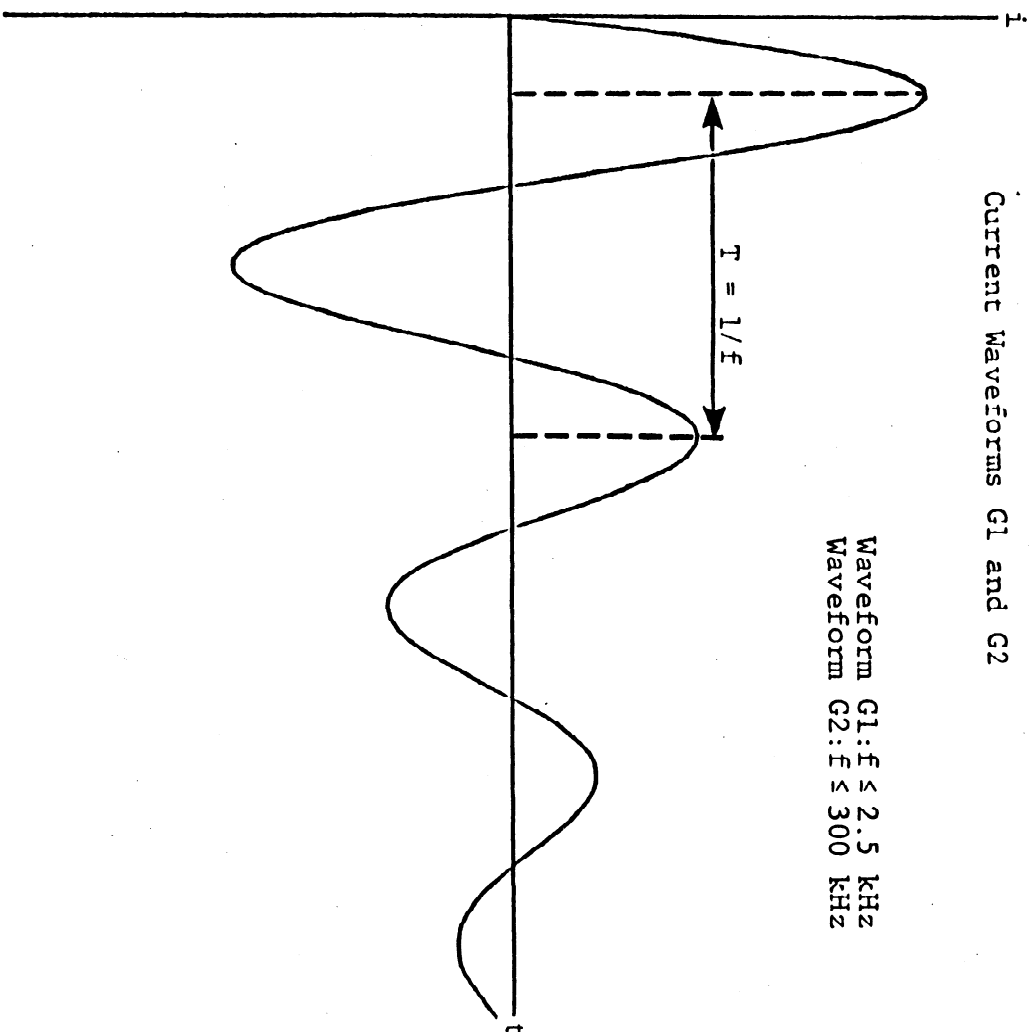


Figure AIII-6. Damped Sinusoidal Current Waveform

APPENDIX IV - Induced Voltage and Current Waveforms

1.0 Purpose. The waveforms described herein are typical of voltages and currents induced in wiring by the external environment.

The internal waveforms are the result of the external lightning characteristics being transferred internally to aircraft systems through various coupling mechanisms. Actual voltage and current waveforms which result from this transfer may be complex but can be separated into one or more of the following waveforms: (1) double exponential, (2) double exponential derivative and (3) damped sinusoidal.

Experience has demonstrated that equipment designed and tested in accordance with the waveforms defined in this appendix will tolerate a wider range of voltage and current waveshapes and frequencies than those actually induced in aircraft wiring.

The equipment transient design level to be applied to a specific system or equipment frequently must be chosen before the airframe is sufficiently detailed to know the internal environment. Many systems are designed with the intent that they will be installed in several different types of aircraft. Therefore, if a specific ETDL is not identified in the individual equipment specification, the equipment manufacturer should design and qualify the equipment to the ETDL consistent with expected use. Suggested ETDLs are identified in Table AIV-1.

2.0 Waveform 1 - Double Exponential Current Waveform. The double exponential (unipolar) current waveform is shown in Figure AIV-1. It is similar to the lightning channel return stroke current waveform (Component A) and represents that portion of the external lightning environment coupled to internal portions of an aircraft by means of structural IR voltages, and apertures.

The internal current waveforms resulting from structural IR voltages and aperture coupling generally follow the external current waveforms. The specific waveform depends upon the relative contribution of these individual coupling mechanisms.

3.0 Waveform 2 - Double Exponential Derivative Voltage Waveform. This voltage waveform, shown in Figure AIV-2 is the classical response of an open circuit to the internal magnetic field. This open circuit voltage is therefore similar to the derivative of Waveform 1. As such, the time to zero crossing (T_2) is equal to the time to peak (T_1) of Waveform 1. Waveform 2 predominates in unshielded, high impedance circuits where magnetic field coupling is the major contributor.

4.0 Waveform 3 - Damped Sinusoidal Voltage or Current Waveform. The damped sinusoidal voltage/current waveform is shown in Figure AIV-3. This waveform is one of the responses to Component A. It will be the only response to very short duration pulses such as Component H. The waveform normally appears in the early time portion of a cable response. In addition, it may also appear later if sparking occurs in the airframe.

The predominant frequencies are often associated with the natural resonances of the aircraft. However, the resonant frequencies of the voltages/currents which are induced in the cable bundles, and within equipments to which such cable bundles connect, will not necessarily be related to the aircraft dimensions.

Because of the large numbers and different lengths of interconnected cables and possible resonance modes of the aircraft, many different frequencies in the range 1 MHz to 50 MHz could be excited. Typical frequencies for this waveform are to be selected from those shown in the Figure AIV-3 table. Waveforms 3A and 3B may be applied for damage assessment by pin injection, and Waveform 3C may be applied for upset or damage assessment by bulk cable injection.

5.0 Waveform 4 - Double Exponential Voltage Waveform. This voltage waveform, shown in Figure AIV-4, is a unipolar waveform representing the potential differences that can appear between interfacing equipment ground references when lightning current flows through the aircraft structure. It represents structural IR potentials and has the same waveshape as the lightning stroke current, Component A. It often predominates in circuits that utilize the airframe as return, and in airframes fabricated of non-metallic materials.

Waveform 4 is also typical of voltages appearing in shielded conductors due to the product of shield current and resistance.

6.0 Waveform 5 - Long Duration Current Waveform. Waveforms from diffusion coupling may have slower rise times and longer durations than those of the external currents, with more conductive structures causing the longer duration waveforms. The long duration current waveform is shown in Figure AIV-5. This waveform represents diffusion and current redistribution effects found on conductors within aircraft structures.

7.0 Suggested Voltage and Current Levels. To provide a means for achieving cost effective systems, a limited number of waveforms and amplitude levels are presented for the purpose of aiding in the establishment of transient control and equipment transient design levels. The levels selected should be representative of the expected environment. Depending upon expected exposure to the lightning environment, it could be appropriate to identify different levels for particular cases.

Table AIV-1 - Suggested ETDL Voltage and Current Levels

Level	Waveform			
	2	3	4	5
	$\frac{V_p \text{ (Volts)}}{I_s \text{ (Amps)}}$	$\frac{V_p \text{ (Volts)}}{I_s \text{ (Amps)}}$	$\frac{V_p \text{ (Volts)}}{I_s \text{ (Amps)}}$	$\frac{V_p \text{ (Volts)}}{I_s \text{ (Amps)}}$
1	50/10	100/4	50/10	N/A
2	125/25	250/10	125/25	N/A
3	300/60	600/24	300/60	300/100
4	750/150	1500/60	750/150	750/1000
5	1600/320	3200/128	1600/320	1600/3k-20k

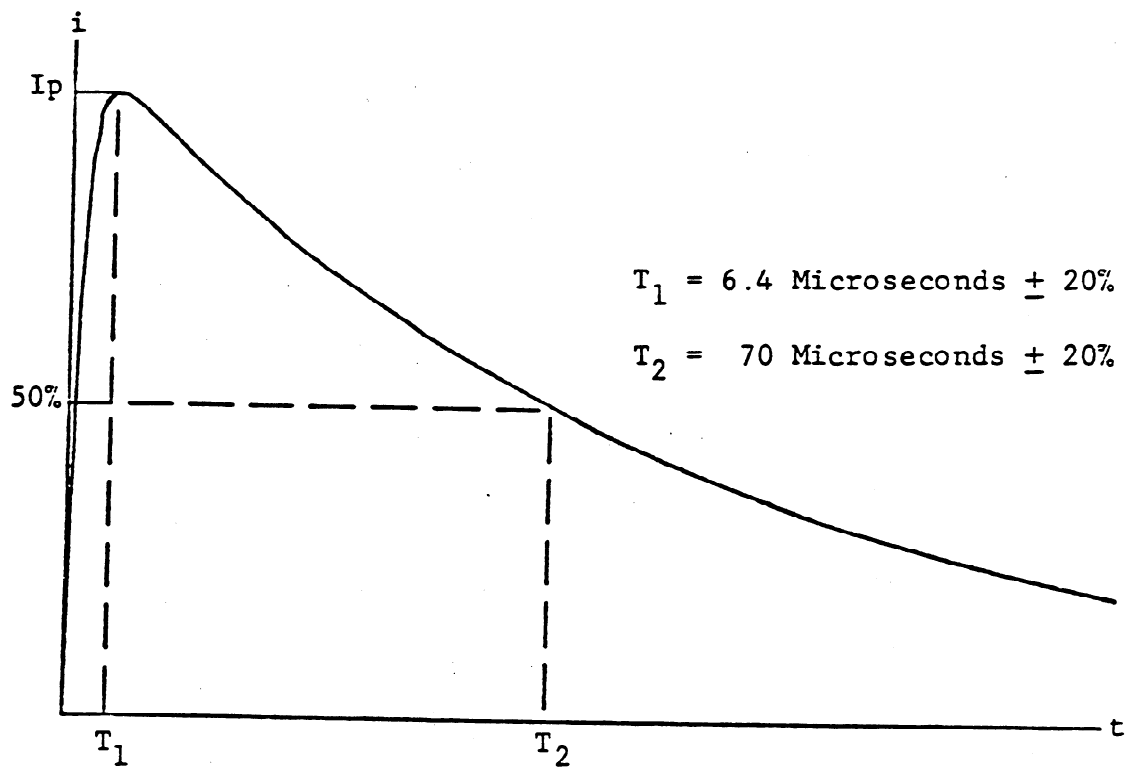
Level 1 is typical for equipment and interconnect wiring that will be installed in a well protected environment.

Level 2 is typical for equipment and interconnect wiring that will be installed in a partially protected environment such as an avionics bay enclosed in an aircraft composed principally of metal.

Level 3 is typical for equipment and interconnect wiring that will be installed in a moderate environment such as the more electromagnetically open areas (e.g., cockpit) of an aircraft composed principally of metal.

Levels 4 & 5 are for equipment and interconnect wiring that will be installed in severe electromagnetic environments. Such levels might be found in all-composite aircraft or exposed areas of an aircraft composed principally of metal, where special shielding practices have not been employed.

Table AIV-1 presents each level in terms of open circuit voltage (V_p) and short circuit current (I_s) at the output terminals of the test generator. The levels are designated V_p (volts)/ I_s (amps).



Note: The amplitude of this waveform is a function of the system and its installation and may vary over a wide range.

Figure AIV-1. Waveform 1 - Double Exponential Current Waveform

3/5/90

AC 20- 136
Appendix 4

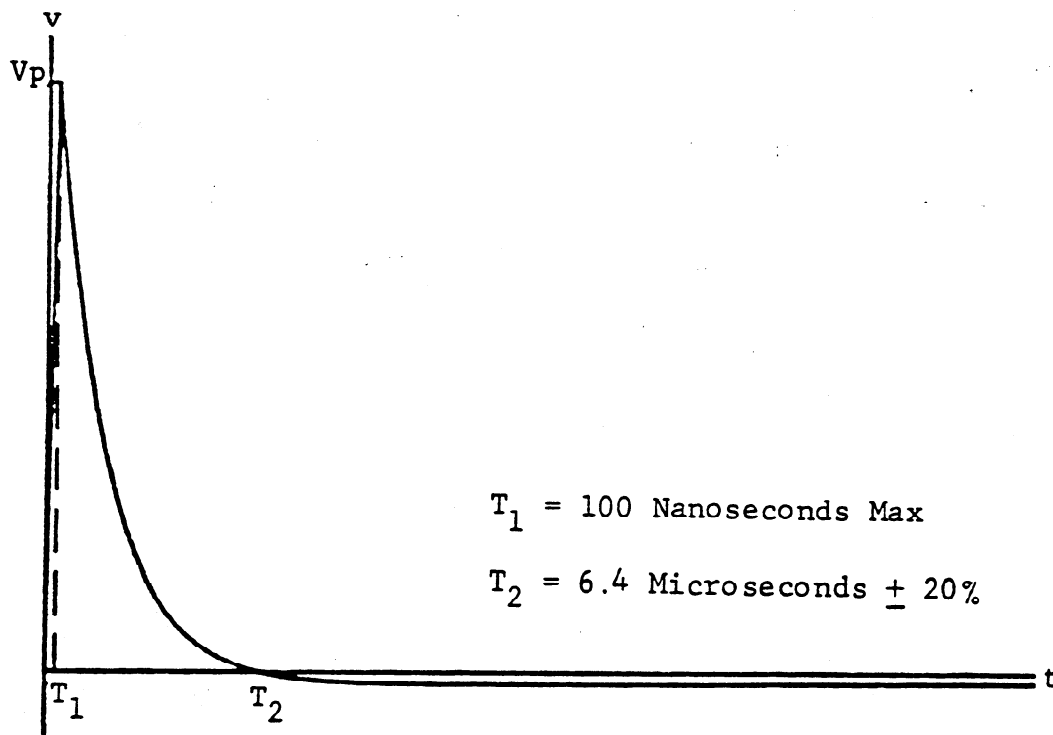
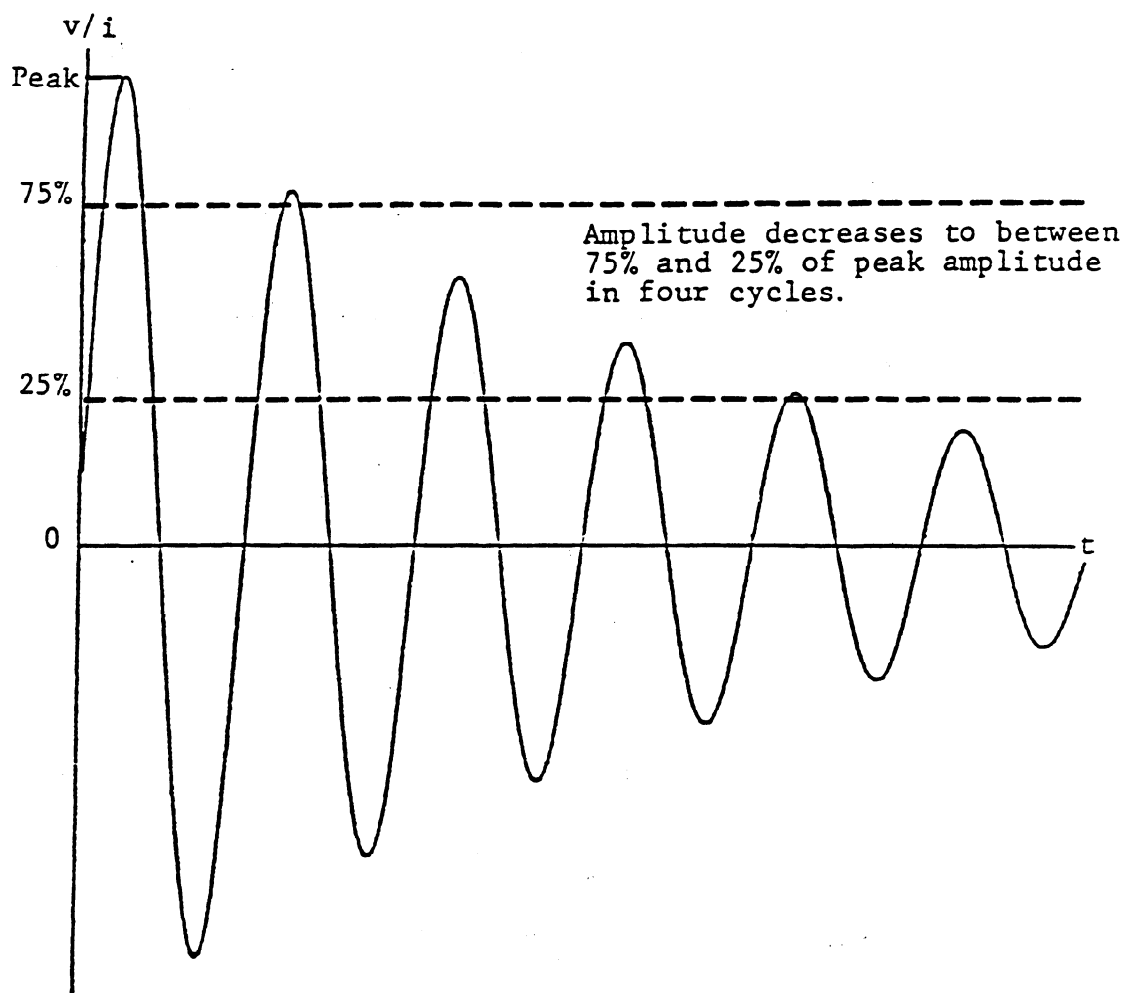


Figure AIV-2. Waveform 2 - Double Exponential Derivative Voltage Waveform



Waveform	Frequency (MHz)	Method	Purpose
3A	10 (\pm 20%)	Pin Injection	Damage
3B	1 (\pm 20%)	Pin Injection	Damage
3C	1 - 50 (as required)	Bulk Cable Injection	Upset/ Damage

Note: Specific frequency(ies) to be selected based upon system response characteristics

Figure AIV-3 - Waveform 3 - Damped Sinusoidal Voltage/Current Waveform

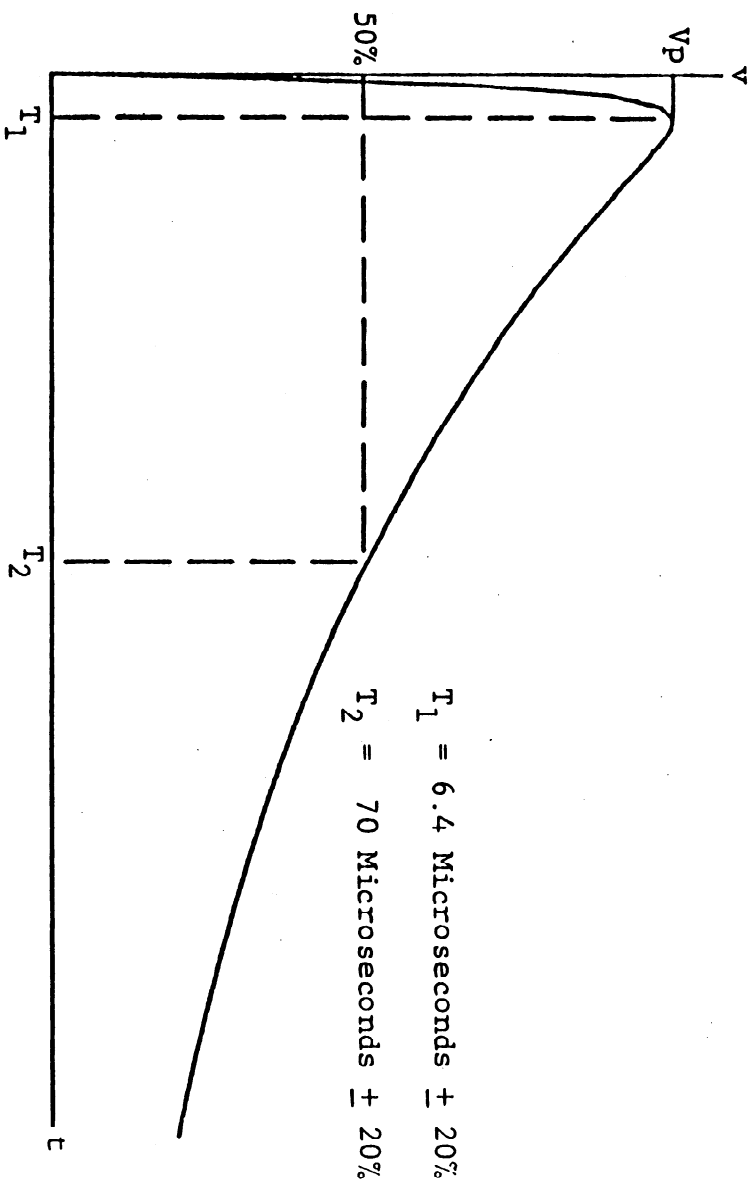
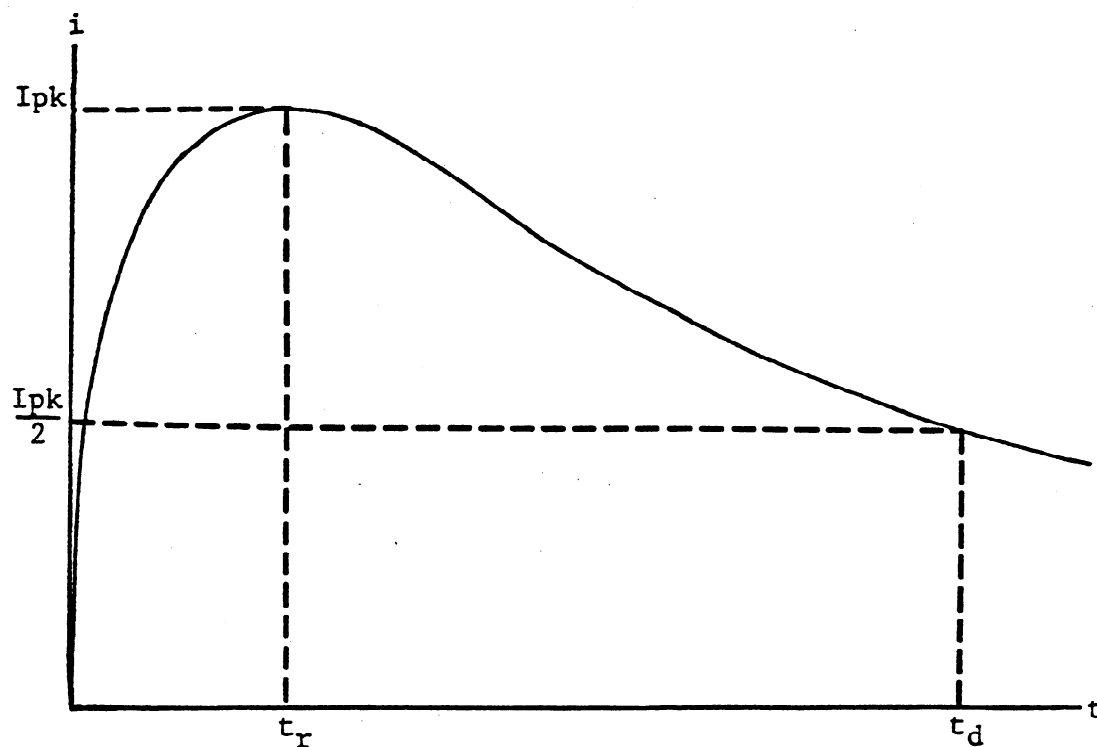


Figure AIV-4. Waveform 4 - Double Exponential Voltage Waveform



Waveform	Airframe Structural Material	Rise time t_r (μs)	Decay time t_d (μs)
5A	Aluminum	40	120
5B	Carbon Fiber Composite (CFC)	50	500

Figure AIV-5 - Waveform 5 - Long Duration Current Waveform

U.S. Department
of Transportation

**Federal Aviation
Administration**

800 Independence Ave., S.W.
Washington, D.C. 20591

Official Business
Penalty for Private Use \$300

Postage and Fees Paid
Federal Aviation
Administration
DOT 515

